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Concentrating solar power – Technology, potential and policy in India

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ABSTRACT

The global demand for energy is growing and conventional energy sources like coal and petroleum are depleting, and renewable resources will play a crucial role in the future. The development of clean and sustainable energy technology is imperative to avert the impending climatic crisis. A worthy investment option is concentrating solar power (CSP) technology which has the capacity to provide for about 7% of the total electricity needs projected for the world by 2030 and 25% by 2050 (considering a high-energy-saving, high-energy-efficiency scenario) [1]. In the present study, the various concentrators available have been explored. Countries all over the world have recognized the potential for CSP and numerous plants are being planned and constructed with incentives offered by the governments. In India, the states of Rajasthan and Gujarat have the potential for widespread application of CSP technology to harness the solar resource. The launch of The Jawaharlal Nehru National Solar Mission (JNNSM) in 2008 by the Indian Government and its initiatives, complemented by state solar policy passed by the states of Rajasthan and Gujarat, will go a long way in the establishment of CSP to supply a segment of India's upcoming energy needs.

Contents

1. Introduction

Energy sources will play an important role in the world's future given that the global demand for energy is rapidly increasing. Estimates of the world primary energy consumption are that 80% of the supply is provided by fossil fuels. Considering various scenarios, the primary energy use is estimated to rise between 32 and 84% by 2050 as compared to 2007 [2]. However, the fossil fuel reserves are rapidly depleting and there is an increasing necessity to substantially reduce greenhouse gases and other pollutants in light of the serious climate crisis that will have to be faced unless developing countries limit carbon emissions from their power sector in the near future [3]. The development of low carbon technologies and their global adoption is therefore an immediate priority which has drawn attention to the new and renewable sources of energy which offer a great potential for satisfying mankind's energy needs with negligible carbon emissions.

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Renewable energy sources are inexhaustible, contrary to fossil fuels, and more widely spread over the Earth's surface [4,5]. Ölz et al. [6] have reported that large hydro, bioenergy, geothermal resources and CSP offer comparable levels of firm capacities to conventional fossil fuel based plants, while sources such as solar Photo Voltaic (PV) applications, wind, and possibly small hydro and wave energy resources in the future, are more variable in terms of the capacity. The Energy Technology Perspectives 2010 [2] states that renewables could account for 48% of power generation in the BLUE Map scenario which sets the goal of halving global energy-related carbon emissions by 2050 (compared to 2005 levels).

The energy from the sun, amounting to nearly 4000 trillion kWh everyday in the form of electromagnetic radiation [7], exceeds the current primary energy supply used by mankind, providing for annual global energy consumption 10,000 times over, which is greatly more than other energy sources available at the ground level, such as geothermic or tidal energy, nuclear power and fossil fuel burning [8]. Environmental protection, economic growth, job creation, diversity of fuel supply and rapid deployment, as well as the global potential for technology transfer and innovation are some of the compelling benefits of solar power [9]. The technology has huge potential where scenarios expect a contribution between 12% and up to 25% of global electricity by 2050 [3,10,11]. Investment in renewable energy, led by wind and solar, reached an all-time high in 2008 and was sustained in 2009 despite the economic downturn.

India's commercial energy consumption has grown rapidly, keeping pace with high economic growth rate. The installed capacity of power in India is about 165 GW as on September 2010. India depends heavily on coal for generating energy as it is apparent from the shares of different sources where in coal was the source for 53.4% of the energy generated, followed by hydropower – 22.6%, gas – 10.6%, nuclear energy – 2.8%, oil – 0.6%, and renewable energy resources – 10% [12]. In terms of global installed renewable capacity, China now ranks second and India fifth [2].

Given India's rapid increased per capita electricity demand, it was realized that sustainable development of India called for growth of energy sector with effective management and proper mix of available renewable and non-renewable sources of energy [13]. The Indian Government has announced a new policy direction on 30th June, 2008 through its National Action Plan on Climate Change (NAPCC) which proposes substantial investment in R&D and infrastructure to increase the share of solar energy within the total energy mix. The Jawaharlal Nehru National Solar Mission (JNNSM), one of the eight National Missions under NAPCC, which was launched on 11th January 2009 with funding of USD930 million, is an ambitious mission to make India a global leader in solar energy generating 20,000 MW of solar power by 2022 [14].

There are two widely used technologies in utilization of solar energy to produce electricity – PV and CSP, where CSP appears to be leading PV for utility-scale power generation, partly due to its maturity and relative cost [15]. CSP, a commercially available technology, uses direct sunlight and mirrors to boil water instead of a fossil fuel as a heat source for producing steam and drive conventional steam turbines [3,16]. The first of the two advantages of CSP over PV is that CSP units can be constructed with an integral thermal energy storage system, thereby providing the capability of generating electricity into the evening hours (generally a peak demand period). Second, solar thermal plants can be equipped with auxiliary burners in order to produce electricity when sunlight is unavailable [15]. Other considerations are that of thermodynamic efficiency and cost of energy per unit area. Not only does converting solar heat into electricity correspond to an efficiency of about 42% against 15% of PV systems but also, to produce the same energy, the collector solar plant requires a site four times smaller than in the case of PV, thus enabling energy production at a price four times lower than PV [17]. According to recent estimates, CSP could produce as much as 7% of the total electricity needs projected for the world by 2030 and 25% by 2050 (considering a high-energy-saving, high-energy-efficiency scenario) [1].

2. The world solar resource

Potential CSP sites around the world are identified using the global distribution of Direct Normal Irradiance (DNI) [18]. In the sunniest countries, the area of the planet with more solar radiation, called "Sun Belt" (North Africa, the Middle East, Mediterranean, California, Arizona, Nevada, New Mexico etc.) which have vast areas with particularly high solar radiation and well suited to large amounts of solar systems, CSP can be expected to become a competitive source of bulk power in peak and intermediate loads by 2020, and of base-load power by 2025–2030 [17,19]. The solar radiation quality limit of potential sites is set to a DNI of at least 2000 kWh per sq. m per year and current projects are being commercially developed for this level of irradiance [18].

The first commercial plants built by Luz International Ltd. began operating in Mojave Desert, California in the period 1984–1991 but a drop in fossil fuel prices then led to dismantling of the policy framework that had supported the advancement of CSP. The market reemerged in Spain and the United states in 2006, in response to government measures such as feed-in tariffs (Spain) and changes in policy to favor solar power generation [19]. Four solar-thermal power plants with a planned overall capacity of around 1000 MW have been approved for construction and operation at the Blythe location in California by the California Energy Commission in September of 2010, contributing to the licensing totaling nearly 3000 MW of large-scale solar power plants in 2010 [20]. For the US it has been estimated that about 118 GW could be installed by 2030 and 1504 GW by 2050 [11]. In Europe around 1500 MW of solar thermal power plants are either recently operating or under construction. The installed capacity in Europe is expected to be of 2000 MW by 2012 and an amount of more than 30,000 MW by 2020 could be reached. Considering a moderate development of the CSP technology, it is expected that 83 GW could be installed in this region by 2030 and 342 GW by 2050, about 55% of this power being installed in the Middle East, 30% in northern Africa and the remaining 15% in Europe [1]. In Spain, there are 81 MW in operation, 839 MW in construction and 10,813 MW under development [11], which exceeds the estimates of the Spanish Renewable Energy Plan for 2005–2010 [1].

The most promising near-term prospect for CSP expansion is that of the export of electricity to Europe from the desert regions of the Middle East and North Africa, which receive some of the most intense solar radiation in the world as mentioned earlier. By using a mere 0.4% of the total surface of the Sahara desert, the European demand for electricity could be entirely met, and the global demand by using only 2% of the total surface. The Union for the Mediterranean composed of European Union (EU) member states and non-EU Mediterranean nations has its main goal as reaching an amount of 20,000 MW installed power in the desert areas of the North African countries by 2020 [3,21].

3. Potential for solar energy in India

India lies in the sunniest regions of the world and the Indian Meteorological Department has compiled data indicating that there are 250–300 clear and sunny days in a year [7]. There is a high potential for solar energy in India, given that both technology routes for conversion of solar radiation into heat and electricity, namely, solar thermal and solar PV being viable to be harnessed providing huge scalability. About 5000 trillion kWh per year energy is incident over India's land area with most parts receiving 4–7 kWh per sq.

m per day [22]. Given present efficiency levels, 1% of land area is sufficient to meet electricity needs of India till 2031 [23].

According to Ministry of New and Renew able Energy (MNRE) [14], the highest annual global radiation is received in Rajasthan and northern Gujarat. The solar resource data and maps developed for Northwestern India describe the potential for widespread application of flat-plate and concentrating solar collectors across this region. The state of Rajasthan receives about 5.5–6.8 kWh of solar radiation per sq. m per day. It is estimated that about 35–50 MW capacity solar power plant can be set up on one sq. kilometer land area according to a recent press release from MNRE [7,14].

The JNNSM will adopt a 3-Phase approach, spanning the remaining period of the 11th five year plan (2007–2012) and first year of the 12th five year plan (up to 2012–2013) as Phase 1. Within the outlines of 11th five year plan, MNRE of the Government of India has announced that it plans to add 50 MW to the electricity generation capacity from solar energy out of the 14,500 MW by 2012 proposed from new and renewable energy resources [14,24]. The focus of first Phase (up to 2013) will be on capturing of the low hanging options in solar thermal; on promoting off-grid systems to serve populations without access to commercial energy and modest capacity addition in grid-based systems. Phase 2 would consist of the remaining 4 years of the 12th five year plan (2013–2017) and the 13th plan (2017–2022) as Phase 3 [22].

Additional targets of JNNSM include creating favorable conditions for solar manufacturing capability, particularly solar thermal for indigenous production and market leadership and ramping up capacity of grid-connected solar power generation to 1000 MW by 2013 with an additional 3000 MW by 2017 through the mandatory use of the renewable purchase obligation by utilities backed with a preferential tariff. The installed power capacity may reach 10,000 MW by 2017. The aspiration is to ensure large-scale deployment of solar generated power for grid-connected as well as distributed and decentralized off-grid provision of commercial energy services. The deployment road map for the technology specifies the target for Phase 1 is to have 7 million sq. m of solar collectors and subsequent targets are 15 million sq. m and 20 million sq. m for Phase 2 and Phase 3 respectively [22].

4. Concentrating solar power (CSP)

CSP technologies only use direct sunlight, concentrating it several times to reach higher energy densities in the focus of solar thermal concentrating systems – and thus higher temperatures when the light is absorbed by some material surface. Heat is then used to operate a conventional power cycle, for example through a steam or gas turbine or a stirling engine, which drives a generator [8]. Hence a typical solar thermal power plant (with a linear geometry) requires the following components: collector array & solar tracking system, absorber, a heat transfer fluid, heat transfer mechanisms, electromechanical devices and if desired, some type of energy storage system and/or hybridization of the solar thermal power plant for attending needs during low and non-solar hours [16]. Hybridising using fossil fuels can be done in several ways including utilizing an auxiliary system for heating the heat transfer fluid during solar transients, or introducing the fossil backup in the steam cycle [25]. CSP has facilitated the production of energy through a system that is not a source of risk or noise for the near populations since it utilizes non-toxic, not flammable and safe materials which have eliminated emissions or pollution [17].

At present, there are four main CSP systems which can be categorized by the way they focus the sun's rays and the technology used to receive the sun's energy. These systems are classified by their focus geometry as either line-focus concentrators (parabolic-trough collectors and linear Fresnel collectors) or as point-focus concentrators (central receiver systems, parabolic dishes and Scheffler systems). The line focus is less expensive and technically less difficult, but not as efficient as point focus. The other classification methodology on the basis of receiver type consists of fixed receivers which are stationary devices that remain independent of the plant's focusing device (linear Fresnel collectors and central receiver systems) and Mobile receivers move together with the focusing device thus collecting more energy (parabolic-troughs and parabolic dishes) [19].

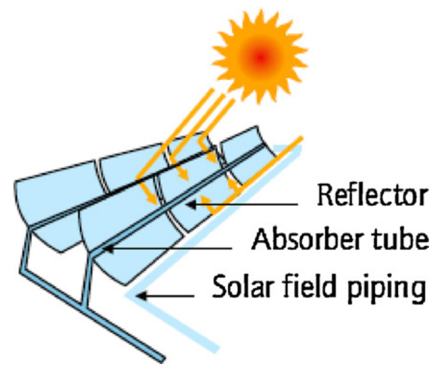

Fig. 1. Parabolic trough [19].

The Scheffler reflector is a small lateral section of a much larger paraboloid. The inclined cut produces the typical elliptical shape of the Scheffler-Reflector. The sunlight that falls onto this section of the paraboloid is reflected sideways to the focus located at some distance of the reflector. Scheffler reflectors are mainly applied for cooking in solar-kitchens.

4.1. Parabolic trough

There is a series of curved mirrors in each parabolic trough which are used to concentrate sunlight on to thermally efficient receiver tubes placed in the trough's focal line through which synthetic oil, heated to approximately 400 °C by the concentrated sun's rays, is used as a heat transfer medium (see Fig. 1). Many parallel rows of these solar collectors usually aligned north to south, span across the solar field. The oil transfers heat from collector pipes to heat exchangers, where water is preheated, evaporated and then superheated. The superheated steam runs a turbine, which drives a generator to produce electricity and the water returns to the heat exchangers after being cooled and condensed [9,19]. With the sunlight concentrated by about 70–100 times, the operating temperatures achieved are in the range of 350–550 °C. The annual solar to electric efficiency is estimated to be 15% [26]. An alternative for the integration of a parabolic trough solar field in a steam turbine power plant is generating steam in the solar field called the direct steam generation technology [25]. Characteristics of the electricity production by stationary parabolic, cylindrical solar concentrator have been discussed in detail by Bojić et al. [27]. The first parabolic trough systems were installed in 1912 near Cairo (Egypt) [26]. The feasibility analysis of constructing parabolic trough solar thermal power plant in Inner Mongolia of China in carried out in a study by Zhao et al. [28] and the result was that the power plant can indeed be operated with its maximum commercial volume and generate power to grid under the support of the state policy. A more recent study by Yang et al. [29] presents the possibility that Tibet, with enough DNI resources and large amount of wasteland, will be a promising candidate site for the construction of Parabolic Trough Solar Thermal Power Plants in China. Nevada Solar One at Boulder City, NV, USA with a capacity of 64 MW, developed by Acciona and operated by Solargenix Energy is an addition to the parabolic trough plants in the year 2007 [30].

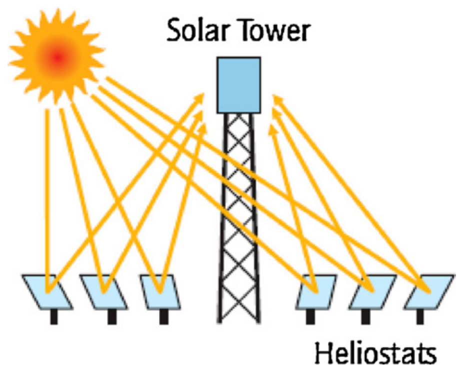

Fig. 2. Solar tower [19].

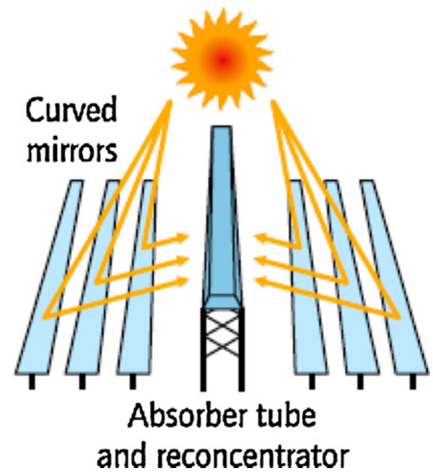

Fig. 4. Linear Fresnel Reflector [19].

4.2. Solar tower (central receiver)

In solar thermal power tower plants, incident sunrays are tracked by large mirrored collectors called heliostats. Data regarding proper heliostats distribution and maintenance strategy around the tower have been presented in a recent study by Zhang et al. [31]. These heliostats concentrate the energy flux on the receiver which is mounted on top of a tower (see Fig. 2) and where energy is transferred to a working thermic fluid at high temperatures of more than 1500 °C, to be used for subsequent generation of electricity as in the case of parabolic troughs. The average solar flux impinging on the receiver has values between 200 and 1000 kW per sq. m which facilitate the high working temperature [32]. Heliostats represent the largest single capital investment in a central receiver plant [33]. The capacity of the solar tower plant is between 10 and 200 MW with annual solar to electric efficiency in the range of 20–35% [9,26]. Heat transfer media including water/steam, molten salts, liquid sodium and air have been identified for large plants with a proposed capacity of 100–200 MW [9]. Large-scale power production with power towers was proven to be feasible by Solar One, which operated from 1982 to 1988 in USA, and was the world's largest power tower plant with a power output of 10 MWe in summer. There were efforts in the early 1980s in countries like Russia, Spain, Japan, and France to establish solar tower systems. In 1996, Southern California Edison and the U.S. Department of Energy redesigned the Solar One plant, called the Solar Two with aims to validate nitrate salt technology along with technical, economic and commercialization aspects of power tower technology. The latest efforts of the USA to increase solar tower energy production include the Sierra Sun Tower which is a 5 MW built in 2009 at Lancaster, CA while a 20 MW power tower system came online in April of the same year outside Seville, Spain [30]. Multi-tower solar arrays (MTSA) are being developed that is based on the concept of a point focusing two-axis tracking concentrating solar power plant with the aim of fulfilling smaller urban capacities. The MTSA, as the name suggests, consists of several closely located tower-mounted receivers positioned such that the heliostat fields of the towers partly overlap. Schramek and Mills [34] reported that the heliostat arrangement allows the MTSA to use radiation previously unutilized in a conventional solar tower system, to obtain high annual ground area efficiency which suggests savings in construction and land costs per installed capacity of the solar power plant.

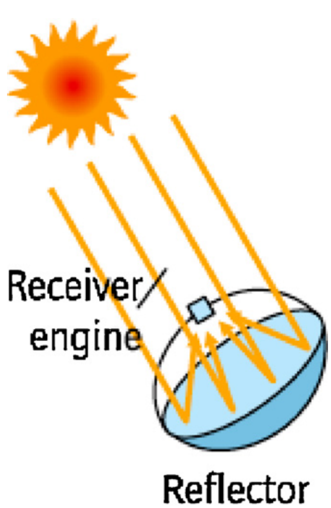

Fig. 3. Parabolic dish [19].

4.3. Parabolic dish

As mentioned earlier, parabolic dish reflector is a point-focus collector that tracks the sun in two axes, concentrating solar energy onto a receiver located at the focal point of the dish (See Fig. 3). The fluid or gas (air) in the receiver is heated to about 750 °C when the focused beam is incident on the receiver. Attached to the receiver is a heat engine/generator unit – stirling engine or a gas turbine which is used to convert the energy stored in the fluid or gas to electricity [35]. Capacities of parabolic dish plants are in the range of 0.01–0.4 MW. The Annual solar to electric efficiency has been reported by Müller-Steinhagen and Trieb [26] to be between 25 and 30%. The dish optical efficiency is considerably higher than that of the trough or tower systems because the mirror is always pointed directly at the sun, whereas the trough and tower suffer from a reduction in projected area, which are called cosine losses, due to a frequent low angle of incidence [9,32]. In a comparison by Lovegrove et al. [36], dishes have shown potential solar to electric conversion efficiencies 50% higher than tower plants and 100% higher than troughs on an equivalent basis of dish, trough and tower systems, with Rankine cycle power generation at the 10 MWe level suggesting that they will perform well economically. A unique feature of dishes is that completely level ground is not a requirement unlike other solar thermal systems [33]. Though dishes are readily applicable in remote applications or smaller isolated grids, a milestone in the dish technology was in 2005 when 20-year power purchase agreements with Stirling Energy Systems for 500 MWe and 300 MWe of solar power to be generated by stirling solar dishes were signed by Southern California Edison and San Diego Gas and Electric respectively [8].

Table 1
Characteristic data for various CSP technologies [9,19,26,33].

	Parabolic trough	Linear Fresnel	Solar tower	Parabolic dish
Capacity (MW)	10–200	10–200	10–200	0.01–0.4
Concentration	70–80	25–100	300–1000	1000–3000
Annual solar-to-electric				
Efficiency	15%	8–10%	20–35% (concepts)	25–30%
Cost: capital				
(Dollars/kW)	3972		4000+	12,578
(Dollars/m^2)	424	234	476	
Cost: O and M				
(Dollars/kWhe)	0.012–0.02	Low	0.034	0.21
Land use (m^2 MWh^{-1} y^{-1})	6–8	4–6	8–12	8–12

4.4. Linear Fresnel

The function of a Fresnel lens is refracting the rays and focusing them at one focal point. A Linear Fresnel Reflector (LFP) consists of an array of linear mirror strips, behaving as a Fresnel lens, which concentrates light on to a fixed receiver mounted on a linear tower (see Fig. 4). The LFR field can be imagined as a broken-up parabolic trough reflector though not parabolic in shape. This modification to parabolic trough reflector lowers efficiency which is compensated for in the form of reduced capital costs given the simple design of flexibly bent mirrors and fixed receivers [19,32]. Reported capacity of a LFR plant is 10–200 MW and the annual solar to electric efficiency lies between 8 and 10% [26]. The largest prototype of a Fresnel collector was set up in 1999 by the Belgian Company, Solarmundo, with a collector width of 24 m and a reflector area of 2500 sq. m [9]. Large plants built in recent years of the LFR type include the Kimberlina Solar Thermal Energy Project at Bakersfield, CA which is a 5 MW built as a demonstration project by Ausra, USA and Ausra's LFR technology is now moving from the prototype stage into commercial deployment [30]. A simple Rankine cycle system for power generation from the steam collected by the solar field in Ausra's solar power plants following which pipes in the absorber carry water which boils and can reach over 285 °C at about 70 times atmospheric pressure. A steam turbine generator is run using this high-pressure steam [37].

5. Comparison of various CSP technologies

A comparative study of the various CSP technologies discussed has been presented in Table 1. The operational and maintenance costs as well as the capital costs are compared. Parabolic trough, linear Fresnel, and solar tower systems are suitable for power generation capacities in the range of 10–200 MW, where as the parabolic dish systems are better suited for lower generation capacity requirements between 0.01 and 0.4 MW. Parabolic trough and linear Fresnel systems have comparable lower concentrations as seen in the table, while solar tower systems show intermediate concentrations in the range of 300–1000, and parabolic dish systems have the highest concentration of 1000–3000. The annual solar to electric conversion efficiency for parabolic trough and linear Fresnel systems is lower as compared to the 25–30% estimated for solar tower and parabolic dish systems. Though efficiency is high for parabolic dish systems, the capital cost as well as the operating and maintenance costs are the highest for these systems, while linear Fresnel systems are noted to have the lowest costs. It can be seen that the land usage of 8–12 sq. m for MW generated per hour per year greatest for solar tower and parabolic dish plants, while the land usage for parabolic trough and linear Fresnel plants are 6–8 and 4–6 sq. m for MW generated per hour per year respectively [9,19,26,33].

6. World initiatives for CSP

According to the IEA [19], governments of developing countries have come to realize that CSP technology is a productive investment given its environmental promise and economic prospects. Since the cost difference between CSP and more conventional power sources is currently an issue, in the short term the deployment of CSP depends on incentives. A number of regions, including Spain, Algeria, some Indian states, Israel and South Africa, have established feed-in tariffs or premium payments.

In order to assist developing countries make CSP competitive in wholesale bulk electricity markets, Clean Development Mechanism under the United Nations Framework Convention on Climate Change (UNFCCC) allows industrialized nations to pay for CO_2 reductions in developing countries [19]. Energy investments in the developing world are sponsored by organizations including the World Bank's Global Environment Facility (GEF), the German Kreditanstalt für Wiederaufbau and the European Investment Bank [9].

Algeria and South Africa have established feed-in tariffs for CSP while Morocco is planning 2 GW of solar plants on five sites from 2010 to 2019, representing 38% of the current installed electric capacity of the country. The European Union's Fifth and Sixth Framework Programs have financed demonstration and commercialization projects in the northern Mediterranean region, especially Spain, Italy and Greece. Spain's "Plan for Promotion of Renewable Energies in Spain" provided incentives for the installation of 200 MW of solar thermal plants by 2010, and motivated major Spanish power market players to launch numerous 50 MW solar thermal projects. In August 2005, the 200 MW limit was raised to 500 MW under the new Renewable Energy Plan 2005–2010 [9,19]. In August of 2010, Spain announced a cut in tariff payments by 45% for solar farms to reduce the premium above the normal electricity price guaranteed for new solar projects.

A study by The Center for Global Development considered the prospects for subsidized promotion of CSP technology for the export of electricity to Europe from sites in Morocco, Libya, and Jordan. In order to achieve the goal of supplying 20% of Europe's total energy from renewable sources, Europeans may accept a higher price for imported renewable electricity, perhaps higher than other potential importing countries. With a generating capacity and associated transmission infrastructure of 20 GW to be installed by 2020, estimates indicate that international clean technology subsidies of nearly USD20 billion spanning over ten years will be needed for the implementation of the project. The profitability of unsubsidized CSP projects is expected to be competitive with that of coal and gas power generation in Europe after the completion of the project [3,19].

7. Indian Government policies

As discussed, the use of CSP technologies in India for the north-western part of the country, particularly in Rajasthan and Gujarat

states, has huge potential to meet its future energy needs. Considering a short time frame, development of solar power by the JNNSM would have to be implemented within the existing framework of the Electricity Act 2003. The National Tariff Policy 2006 which currently mandates the State Electricity Regulatory Commissions to fix a minimum percentage of energy purchase from renewable sources of energy would be modified to mandate that the state electricity regulators fix a percentage for purchase of solar power. Starting with 0.25% in the Phase I as the solar power purchase obligation for states would be advisable with plans to increase it to 3% by 2022.

One of the options in promoting setting up of a large number of solar power projects with the consideration of minimizing the impact on tariff, is to bundle solar power along with power out of the cheaper unallocated quota of central stations and selling this bundled power to state distribution utilities at the Central Electricity Regulatory Commission of India (CERC) regulated price. The gap between average cost of power and sale price of power would be minimized. NTPC Vidyut Vyapar Nigam Ltd. (NVVN), a wholly owned subsidiary company of NTPC, will undertake the sale of the bundled power to state utilities at the rates determined as per CERC regulations and those state utilities will be entitled to use the solar part of the bundled power for meeting their renewable purchase obligations under the Electricity Act, 2003 [22].

Rajasthan state is in the advanced stage of preparedness for installation of grid Interactive solar power plants of more than 500 MW in next 2–3 years based on the progressive views adopted in past five years in respect of solar generation policy issued under Government of Rajasthan for harnessing renewable energy in Rajasthan in year 2004. Demonstration projects being set up in the state of Rajasthan under JNNSM's initiatives include a 50–100 MW Solar thermal plant with 4–6 h storage (which can meet both morning and evening peak load and double plant load factor up to 40%), a 100 MW Parabolic trough technologies based solar thermal plant, a 100–150 MW solar hybrid plant with coal, gas or bio-mass to address variability and space-constraints and a 20–50 MW Solar plant with or without storage, based on central receiver technology with molten salt/steam as working fluid and other emerging technologies [38].

The Rajasthan Solar Policy, 2010 was issued by the Government of Rajasthan, Energy Department, with one of the objectives being developing a global hub of solar power of 10,000–12,000 MW capacity in next 10–12 years to meet some of the energy requirements of Rajasthan and India. The state has sanctioned 66 MW solar power projects in compliance of the Rajasthan Electricity Regulatory Commission's orders and will promote deployment of utility grid power to be connected at 33 kV and above level which shall be procured by NVVN as per mechanism provided under JNNSM Phase-1. The Rajasthan state will develop 50 MW SPV and 50 MW solar thermal power plants by selection of developer through tariff based competitive bidding process on concept of bundling of solar power with equivalent amount of MW capacity of conventional power. The state shall promote setting up of solar power projects for direct sale to state distribution utilities with the target of developing a maximum capacity of 100 MW for Phase-1 (up to 2013) and an additional 250 MW for Phase-2 (2014–2017). Solar Parks of more than 1000 MW capacity in identified areas of Jaisalmer, Bikaner, Barmer and Jodhpur districts in various stages will be developed with the state acting as the facilitator to attract global investment in Rajasthan and will provide the necessary infrastructure, regulatory and other Government support required through a Nodal Agency to rapidly ramp up Solar power generation capacity in the state [38].

The Government of Gujarat, in order to promote grid connected solar energy generation, has also come out with Solar Power Policy, 2009 which envisages installation of 500 MW solar power generation and tariff for electricity generated from the PV and solar thermal power projects where the minimum project capacity of each solar thermal plant should be 5 MW [39]. The Government of Gujarat has allotted 716 MW of solar power capacity, of which 351 MW is from solar thermal technology, to 34 national and international project developers against the capacity of 500 MW mentioned above. Investment of over INR 120,000 million would be coming into the state in the next few years and estimates indicate that the 716 MW of solar power would generate 1250 Million Units of green energy annually [40].

8. Conclusion

In light of the necessity to tackle climate change, energy produced from renewable sources is gaining importance. Solar thermal technologies with promising low carbon emissions will play an important role in global energy supply in the future. As of early 2010, the global stock of CSP plants neared 1 GW capacity. A number of projects being developed in countries including USA, Spain, India, Egypt, Morocco, and Mexico are expected to total 15 GW. Numerous countries including India have taken up the opportunity to harvest the solar resource [19]. CSP projects have the potential to be competitive with conventional power generation sources in the near future. World governments are actively announcing incentives for development of solar thermal power plants and establishing policy frameworks. The launch of The JNNSM by MNRE, Government of India is the first step in the promotion and establishment of solar energy as a viable alternative to conventional sources. The establishment of feed-in tariffs and other incentives, passing dynamic government policies, and the cooperation of industry, researchers and other stakeholders will play crucial role in the development of CSP technology and its deployment for attaining energy goals of the future.

References

[1] Izquierdo S, Montanes C, Dopazo C, Fueyo N. Analysis of CSP plants for the definition of energy policies: the influence on electricity cost of solar multiples, capacity factors and energy storage. Energy Policy 2010;38:6215–21.
[2] IEA. Energy technology perspectives 2010. Paris: International Energy Agency; 2010.
[3] Ummel K, Wheeler D. Desert power: the economics of solar thermal electricity – for Europe, North Africa, and the Middle East. Working paper. Center for Global Development; 2008. p. 156.
[4] Braun FG, Hooper L, Wand R, Zloczysti P. Innovation in concentrating solar power technologies: a study drawing on patent data. Discussion papers. Berlin: DIW Berlin, German Institute for Economic Research; 2010.
[5] Philibert C. International technology collaboration and climate change mitigation – case study 1: concentrating solar power technologies. Technical report. Paris: International Energy Agency; 2004, <http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=1025> [accessed 21.09.10].
[6] Ölz S, Sims R, Kirchner N. Contribution of renewables to energy security. IEA information paper. Paris: International Energy Agency; 2007.
[7] Gupta PK. Renewable energy sources – a longway to go in India. Renewable Energy 1999;16:1216–9.
[8] Philibert C. The present and future use of solar thermal energy as a primary source of energy. Solar thermal energy. Technical report. Paris: International Energy Agency; 2005, <http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=1574> [accessed 21.09.10].
[9] Aringhoff R, Brakmann (ESTIA) G, Geyer (IEA SolarPACES) M, Teske (Greenpeace) S. Concentrated solar thermal power – now! Technical report. ESTIA, Brussels: Greenpeace International, Amsterdam, IEA SolarPACES Implementing Agreement, Almeria; 2005.
[10] IEA, IEA factsheet – renewable energy essentials: concentrating solar thermal power. Paris: International Energy Agency; 2009, <http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=2191> [accessed 21.09.10].
[11] Richter C, Teske S, Short R. Greenpeace International, SolarPACES, and ESTELA, Concentrating solar power. Global outlook 09, 2009, <http://www.solarpaces.org> [accessed 30.10.10].
[12] CEA. All India regionwise generating installed capacity (MW) of power utilities including allocated shares in joint and central sector utilities. Central Electricity Authority; 2010, <http://www.cea.nic.in/power_sec_reports/executive_summary/2010_09/8.pdf> [accessed 29.10.2010].

[13] MNRE, Akshay Urja. Ministry of New and Renewable Energy Government of India 2009;2(5):20–23, <http://www.mnre.gov.in> [accessed 29.10.2010].

[14] MNRE. Ministry of New and Renewable Energy Government of India, <http://www.mnre.gov.in> [accessed 29.10.2010].

[15] Holbert KE. Impact of solar thermal power plants on water resources and electricity costs in the southwest. In: Proc. North American power symposium (NAPS). 2009. p. 1–6, doi:10.1109/NAPS.2009.5483989, <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5483989&isnumber=5483979>.

[16] Ortiz-Rivera EI, Feliciano-Cruz LI. Performance evaluation and simulation of a solar thermal power plant. In: Proc. energy conversion congress and exposition. 2009. p. 337–44, doi:10.1109/ECCE.2009.5316215, <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5316215&isnumber=5315930>.

[17] Brenna M, Foiadelli F, Roscia M, Zaninelli D. Evaluation of solar collector plant to contribute climate change mitigation. In: Proc. international conference on sustainable energy technologies. 2008. p. 198–202, doi:10.1109/ICSET.2008.4747001, <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4747001&isnumber=4746961>.

[18] Breyer C, Knies G. Global energy supply potential of concentrating solar power. In: Proc. SolarPACES 2009. 2009.

[19] IEA. Technology roadmap – concentrating solar power. Paris: International Energy Agency; 2010, <http://www.iea.org/papers/2010/csp_roadmap.pdf> [accessed 21.09.10].

[20] CEC. The California Energy Commission. Press release: 29 Sept. 2010, <http://www.energy.ca.gov> [accessed 29.10.10].

[21] ESTELA. Solar power from Europe's sun belt – a European solar thermo-electric industry initiative contributing to the European Commission Strategic Energy Technology Plan. Brussels: European Solar Thermal Electricity Association; 2009.

[22] JNNSM. Mission document, Ministry of New and Renewable Energy Government of India. Jawaharlal Nehru National Solar Mission; 2009, <http://mnre.gov.in/pdf/mission-document-JNNSM.pdf> [accessed 29.10.2010].

[23] Ghosh P. National Action Plan on Climate Change. Technical presentation. Prime Minister's Council on Climate Change; Oct. 2009. Ministry of Environment and Forests, Government of India, <http://moef.nic.in/downloads/others/CC_ghosh.pdf> [accessed 03.11.10].

[24] Purohit I, Purohit P. Techno-economic evaluation of concentrating solar power generation in India. Energy Policy 2010;38:3015–29.

[25] Fernandez-Garcia A, Zarza E, Valenzuela L, Perez M. Parabolic-trough solar collectors and their applications. Renewable and Sustainable Energy Reviews 2010;14:1695–721.

[26] Müller-Steinhagen H, Trieb F. Concentrating solar power – a review of the technology. Ingenia – Quarterly of the Royal Academy of Engineering. 18 Feb.–Mar. 2004.

[27] Bojić M, Marjanović N, Miletić I, Malešević J, Mitić A. Some characteristics of electricity production by stationary parabolic, cylindrical solar concentrator. In: Proc. 8th international symposium on advanced electromechanical motion systems & electric drives joint symposium. 2009. p. 1–4, doi:10.1109/ELECTROMOTION.2009.5259147, <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5259147&isnumber=5259072>.

[28] Zhao M, Liu Z, Zhang Q. Feasibility analysis of constructing parabolic trough solar thermal power plant in inner Mongolia of China. In: Proc. Asia-Pacific power and energy engineering conference. 2009. p. 1–4, doi:10.1109/APPEEC.2009.4918378, <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4918378&isnumber=4918026>.

[29] Yang B, Zhao J, Yao W, Zhu Q. Feasibility and potential of parabolic trough solar thermal power plants in Tibet of China. In: Proc. Asia-Pacific power and energy engineering conference (APPEEC). 2010. p. 1–4, doi:10.1109/APPEEC.2010.5448314, <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5448314&isnumber=5448125>.

[30] EESI. Concentrated solar power – focusing the sun's energy for large scale power generation. Fact sheet. Environmental and Energy Study Institute; 2009.

[31] Zhang H, Wang Z, Guo M, Liang W. Cosine efficiency distribution of heliostats field of solar thermal power tower plants. In: Proc. Asia-Pacific power and energy engineering conference. 2009. p. 1–4, doi:10.1109/APPEEC.2009.4918245, <http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=4918245>.

[32] Kalogirou SA. Solar thermal collectors and applications. Progress in Energy and Combustion Science 2004;30:231–95.

[33] Nixon JD, Dey PK, Davies PA. Which is the best solar thermal collection technology for electricity generation in north-west India? Evaluation of options using the analytical hierarchy process. Energy 2010, doi:10.1016/j.energy.2010.07.042.

[34] Schramek P, Mills DR. Multi-tower solar array. Solar Energy 2003;75: 249–60.

[35] Kongtragool B, Wongwises S. A review of solar-powered stirling engines and low temperature differential stirling engines. Renewable and Sustainable Energy Reviews 2003;7:131–54.

[36] Lovegrove K, Zawadski A, Coventy J. Paraboloidal dish solar concentrators for multi-megawatt power generation. In: Proc. solar world congress. 2007.

[37] Ausra. An Introduction to solar thermal electric power. Technical report. Ausra; 2007, <http://www.ausra.com/pdfs/SolarThermal101_final.pdf> [accessed 03.11.10].

[38] GoR. Rajasthan Solar Policy. Government of Rajasthan – Energy Department; 2010, <http://www.indiaenvironmentportal.org.in/files/Solar%20Policy%20_2010.pdf> [accessed 14.10.10].

[39] GoG. Solar Power Policy. Government of Gujarat – Energy and Petrochemicals Department; 2009, <http://gidb.org/downloads/solarp.pdf> [accessed 14.10.10].

[40] GEDA. Capacity allotment for solar power project development in Gujarat. Gujarat Energy Development Agency; 2009, <http://www.geda.org.in/pdf/solar_allotment_webnote.pdf> [accessed 14.10.10].